

CLAIMS

1. A method for detecting at least one nodule in a medical image of a subject, comprising:
 - identifying, in said medical image, an anatomical region corresponding to at least a portion of an organ of interest;
 - filtering said medical image to obtain a difference image;
 - detecting, in said difference image, a first plurality of nodule candidates within said anatomical region;
 - calculating respective nodule feature values of said first plurality of nodule candidates based on image pixel values of at least one of said medical image and said difference image;
 - removing false positive nodule candidates from said first plurality of nodule candidates based on said respective nodule feature values to obtain a second plurality of nodule candidates; and
 - determining said at least one nodule by classifying each of said second plurality of nodule candidates as a nodule or a non-nodule based on at least one of said image pixel values and said respective nodule feature values.
2. The method of claim 1, wherein the identifying step comprises:
 - forming a histogram of gray values of pixels in said medical image;
 - determining a gray-level threshold using said histogram; and
 - identifying an outline of said anatomical region using said gray-level threshold.
3. The method of claim 1, wherein the identifying step comprises:
 - identifying, in a low-dose computed tomographic (LDCT) image, a lung region of said subject.
4. The method of claim 1, wherein the filtering step comprises:
 - filtering said medical image using a matched filter to obtain a nodule-enhanced image;
 - filtering said medical image using a ring-average filter to obtain a nodule-suppressed image; and
 - subtracting said nodule-suppressed image from said nodule-enhanced image to obtain said difference image.
5. The method of claim 1, wherein the detecting step comprises:

forming initial regions within said anatomical region;
selecting said first plurality of nodule candidates based on said initial regions, each nodule candidate in said first plurality of nodule candidates having a respective nodule region including one of said initial regions; and
determining said respective nodule regions of each nodule candidate in said first plurality of nodule candidates using region growing.

6. The method of claim 5, wherein the forming step comprises:
forming a histogram of gray values of pixels in said difference image; and
determining said initial regions using multiple-gray-level thresholding of said histogram.
7. The method of claim 5, wherein the selecting step comprises:
calculating respective effective diameter and circularity values for each of said initial regions; and
selecting said first plurality of candidate nodules based on said respective effective diameter and circularity values of each of said initial regions.
8. The method of claim 5, wherein the determining step comprises:
determining a respective center pixel having a maximum pixel value within each respective nodule region;
calculating, for a first respective subregion that includes said respective center pixel within each respective nodule region, at least one first morphological image feature, said first respective subregion defined as those pixels having a pixel value above a first pixel threshold, but less than said maximum pixel value;
calculating, for a second respective subregion that includes said respective center pixel within each respective nodule region, at least one second morphological image feature, said second respective subregion defined as those pixels having a pixel value above a second pixel threshold, but less than said maximum pixel value; and
determining said respective nodule region of each nodule candidate based on respective differences between the at least one first morphological image feature and the at least one second morphological image feature.

9. The method of claim 1, wherein the calculating step comprises:
determining, for each candidate nodule in said first plurality of candidate nodules, at least one respective morphological feature value, including at least one of effective diameter, circularity, and irregularity; and
determining, for each candidate nodule in said first plurality of candidate nodules, at least one respective gray level feature value, including at least one of a nodule contrast in said difference image, a nodule contrast in said medical image, a nodule contrast of a nodule outer region, and a standard deviation of said nodule outer region.

10. The method of claim 9, wherein the removing step comprises:
removing false positive nodule candidates from said first plurality of nodule candidates based on said at least one respective morphological feature value and said at least one respective gray level feature value.

11. The method of claim 1, wherein the calculating step comprises:
determining, for each candidate nodule in said first plurality of candidate nodules, at least one respective interior feature value, including one of an average pixel value, full width at half maximum (FWHM), and full width at tenth maximum (FWTM), based on pixel values in an interior region of each candidate nodule; and
determining, for each candidate nodule in said first plurality of candidate nodules, at least one respective exterior feature value, including one of an average pixel value, full width at half maximum (FWHM), and full width at tenth maximum (FWTM), based on pixel values in an exterior region of each candidate nodule.

12. The method of claim 11, wherein the removing step comprises:
removing false positive nodule candidates from said first plurality of nodule candidates based on said at least one respective interior feature value, said at least one respective exterior feature value, and respective locations of the nodule candidates within said anatomical region.

13. The method of claim 1, wherein the determining step comprises:
determining said at least one nodule from said second plurality of nodule candidates based on said image pixel values using a Multi-MTANN (Massive Training Artificial Neural Network).

14. The method of claim 13, wherein the determining step comprises:
training a plurality of MTANNs to distinguish nodules from a respective type of non-nodules; and

classifying, based on said image pixel values, said second plurality of nodule candidates using said plurality of trained MTANNs to obtain said at least one nodule.

15. The method of claim 1, wherein the determining step comprises:
determining, based on said respective nodule feature values, said at least one nodule from said second plurality of nodule candidates using a linear discriminant analysis.

16. A computer program product storing program instructions for execution on a computer system, which, when executed by the computer system, cause the computer system to perform the method recited in any one of claims 1-15.

17. A system configured to detect said at least one nodule in said medical image of said subject by performing the steps recited in any one of claims 1-15.